Proc. NIPR Symp. Polar Biol., 8, 69–73, 1995

DIEL CHANGES IN THE VERTICAL DISTRIBUTION AND FEEDING ACTIVITY OF COPEPODS IN ICE-COVERED RESOLUTE PASSAGE, CANADIAN ARCTIC (EXTENDED ABSTRACT)

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Under sea-ice, copepods feeding on an algal community is one of the most important processes of food web dynamics just as in open water. Some studies of the vertical migration and feeding activity of copepods have been carried out in the northern Arctic of Canada (*cf.* CONOVER and HUNTLEY, 1991). However, simultaneous measurements of ingestion rate and vertical migration of copepods have seldom been attempted (CONOVER *et al.*, 1988; RUNGE and INGRAM, 1988). It is necessary to investigate the diel changes in vertical distribution and feeding of copepods in order to understand the energy flow from the algal community to copepods in the ice-covered area. Our goal in this study was to understand the role of copepods in the marine ecosystem under sea-ice.

Field investigation was carried out in Resolute Passage (74°41.19′N, 95°15.59′W) during May 16 to 25, 1992. Observations of vertical distribution, biomass and gut pigment contents of copepods were carried out 9 times during May 16 and 17. Samples were collected from 0, 1 and 3 m layers from the under-surface of the sea-ice using the NIPR-net (FUKUCHI *et al.*, 1979) with 100 μm mesh. Zooplankton were also sampled from 3–15, 15–30 and 30–130 m layers, by vertical tow of a closing ring-net (50 cm dia.) with 100 μm mesh. To determine the gut clearance rate, copepods were collected 18 times a day from 0 m from the under-surface of the ice and 8 times a day from 10 m from the under-surface of the ice with the NIPR-net during May 20 and 21. Gut clearance rates and ingestion rates of individual copepods were measured and calculated by the gut fluorescence method of SAITO *et al.* (1991), without homogenizing the samples. The ingestion rate of the copepod population was obtained from the ingestion rate and concentration of the copepods. To observe the difference between daytime and nighttime feeding activity, bottle experiments were carried out for the functional response of ingestion rate to the ice-algae. The experiments were conducted 8 times from May 22 to 25, according to FROST (1972). Water samples for chlorophyll measurement were collected 3 times from 7 layers by NISKIN-Bottle, and photosynthetically active radiation (PAR) was measured using LICOR cosine collectors set on the ice and at 5 m from the under-surface of the ice during May 16 and 17.

Light and chlorophyll

Seventy-seven pairs of irradiance (PAR) on the ice and at 5 m from the under-surface of the ice were measured. Despite 24 hours of continuous daylight, diel changes in the irradiance were observed at both sites. Irradiance on the ice ranged from 100×10^{19} to 130×10^{19} Quanta $m^{-2}s^{-1}$ in the daytime between 0800 and 1800 and from 5×10^{19} to 40×10^{19} Quanta $m^{-2}s^{-1}$ in the nighttime between 2000 and 0400. Irradiance at 5-m was about 0.04% and 0.1% of the value on the ice in daytime and nighttime, respectively. Chlorophyll *a* concentrations in the water were very low, showing no more than 0.14 $\mu g\,l^{-1}$ (when phaeopigment was added, it was less than 0.35 $\mu g\,l^{-1}$). The concentration was relatively high in the upper layers (0, 2.5 and 5 m) ranging from 0.08 to 0.14 $\mu g\,l^{-1}$, and it decreased with depth to 0.01–0.03 $\mu g\,l^{-1}$ at 100 m. Little difference was observed in each layer between daytime and nighttime.

Copepod distribution and feeding

Copepods numerically dominated the zooplankton, accounting for 97.5% of total zooplankton in the water column throughout the day. Among copepods, *Pseudocalanus* spp. were abundant accounting for 91.6% of the copepods. When we consider the energy transport from algae to zooplankton, *Pseudocalanus* was the key species in Resolute Passage. Under continuous daylight condition, diel changes of abundance of *Pseudocalanus* spp. were observed in each layer (Fig. 1). Stage V was the most abundant in each layer and stages III to V ascended from 3–15-m to 0-m at 1800. However, they descended from 0-m before midnight and did not stay at 0-m throughout "nighttime". They descended to the 3–15-m layer around 0600.

During observation of diel vertical migration, diel changes of gut pigment contents of *Pseudocalanus* spp. were measured in the 5 layers. Clear diel change was observed at 0-m, with high gut pigment contents in daytime (*e.g.* Stage V; 1.14–1.59 ng $indi.^{-1}$) and low in nighttime (*e.g.* Stage V; 0.42–0.84 ng $indi.^{-1}$). Comparing the nighttime contents to those in daytime, it seemed that *Pseudocalanus* did not obtain enough food during nighttime. In open and ice-covered waters, gut pigment contents are generally higher in nighttime than in daytime (HEAD *et al.*, 1985; RUNGE and INGRAM, 1988). The diel change in gut pigment contents observed here was a mirror image of the usual pattern. This unusual feeding cycle was also observed by CONOVER *et al.* (1986) at the 0-m in Resolute Passage. They argued that the tidal cycle controlled ice-algal feeding and this feeding rhythm was impeded by tidal currents so that optimal feeding conditions would occur as currents decreased toward slack water. In this study, however, higher gut pigment contents were not only observed at slack water. There appears to be another factor controlling individual feeding rhythm because the bottle experiments showed no large difference in the functional response of ingestion rate between daytime and nighttime. This result of the experiment revealed that *Pseudocalanus* could graze a similar amount of algae between daytime and nighttime when *Pseudocalanus* wanted to obtain algae. At 0 m, favorable nutritional condition for every stage should prevail in daytime, but not all stages came up to the 0 m. Our results indicate that

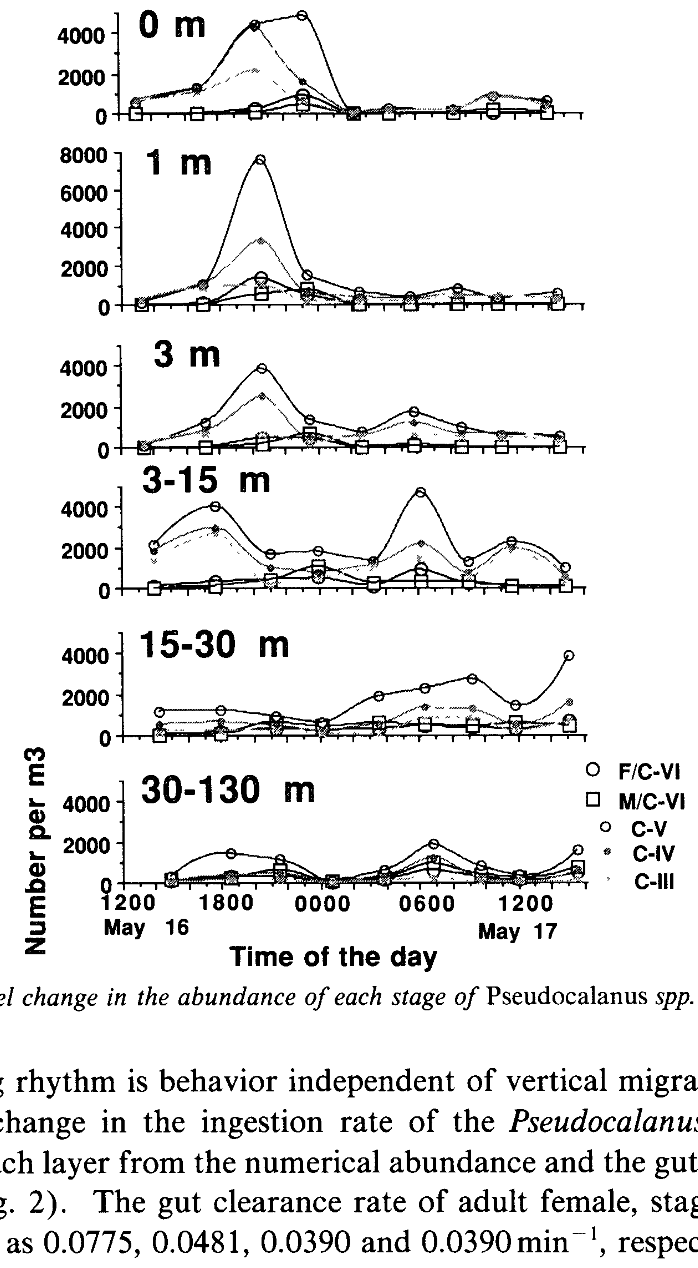

Fig. 1. Diel change in the abundance of each stage of Pseudocalanus *spp. in each layer.*

the diel feeding rhythm is behavior independent of vertical migration.

The diel change in the ingestion rate of the *Pseudocalanus* population was calculated in each layer from the numerical abundance and the gut clearance rate of each stage (Fig. 2). The gut clearance rate of adult female, stages V, IV and III were measured as 0.0775, 0.0481, 0.0390 and 0.0390 min^{-1}, respectively. Ingestion of the population was high in the 0- and 1-m layers reaching more than 20 $\mu g\,m^{-3}\,h^{-1}$ in nighttime around 2000. The rates were very low at 0000 and 0700. Figure 2 shows that the principal source of under-ice nutrition for *Pseudocalanus* was derived from ice algae, because phytoplankton chlorophyll concentration in the water was too low to support ingestion even if the doubling time of the phytoplankton was 3 day^{-1} or more. Total daily ingestion in the top 0–3 m and 0–130 m water columns were calculated as 0.32 and 2.69 $mg\,m^{-2}\,day^{-1}$, respectively. Ice algal production in Resolute Passage from February to July was 58–207 $mgC\,m^{-2}\,day^{-1}$ with carbon chlorophyll ratio of 11 to 27 (Kudoh, personal commun.). When the median values of the production and carbon chlorophyll ratio were used for calculation, the population of *Pseudocalanus* in the 0–3 m and 0–130 m water column consumed about 4.5 and 38.6% of the ice algal production, respectively. When ice algal sedimentation is obtained, these percentages (or daily consumptions)

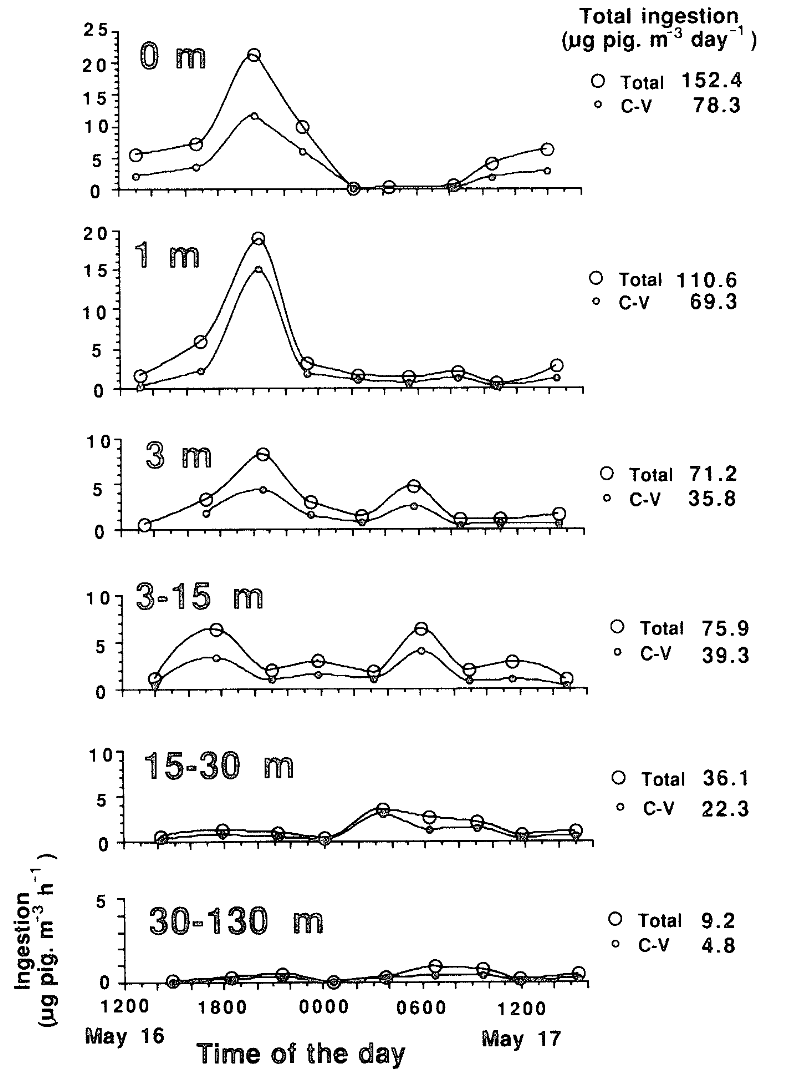

Fig. 2. Diel changes of ingestion rate of total Pseudocalanus *spp. (open circle) and* Pseudocalanus *spp. stage V (filled circle) populations in each layer. Total ingestion rate in each layer is shown on right side.*

will become important to estimate the pathway, especially the contributions of ice algae to the benthic and pelagic environment under sea ice.

The following questions are still open: 1) why did copepods descend from 0-m before midnight, 2) why did copepods obtain so little food during midnight and morning, 3) what was the major food source of copepods and 4) sedimentation of ice algae. When the answers to these questions become clear, the role of copepods in the under-ice food web will become clear.

This study was a part of the SARES project funded in part by a Canada–Japan Complementary Study (1989) under the Japan-Canada Science and Technology Cooperation Agreement. We thank Dr. L. FORTIER, University Laval, for critically reading the manuscript. Special thanks to the PCSP, Canada for supplying accommodations and logistics in Resolute Passage. A contribution to the research programs of GIROQ and of Institute Maurice-Lamontagne (Canada). Part of the project was supported by a grant from the Monbusho International Science Research Program (#03044146).

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(Received April 11, 1994; Revised manuscript received July 20, 1994)